Small Aircraft Propulsion for Personal Air Transportation

The Challenge

SATS Planning Conference

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SATS 2001

Small Aircraft Propulsion
Technologies For The Future

2003

100 knot

250 knot

Personal VTOL
"Doorstep to Destination"
Ultra-Safe All-Weather

2010

~$25,000

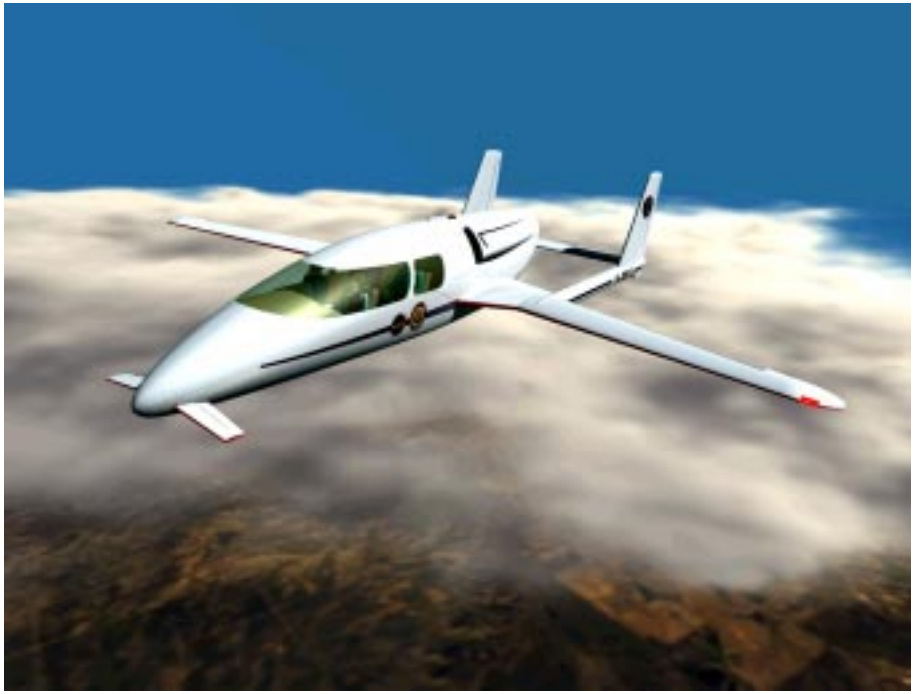
400 knot

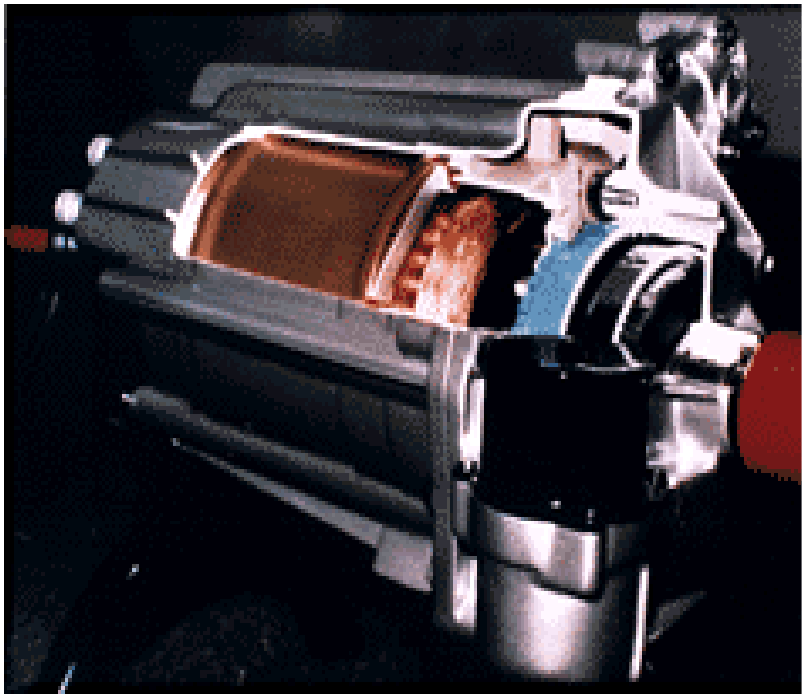
- Whisper-quiet, ultra-light, low-cost propulsion systems
  - Engines
  - Propellers & Rotors
  - Transmissions with high reduction ratio gearing
- Low-cost ultra-low emissions
- Failsafe, affordable flight/propulsion Supervisor
  - Intelligent - configures & controls aircraft/propulsion system
    - = Pilot guides vehicle, supervisor flies and controls it
    - = Reconfigures systems & advises pilot when malfunction occurs
- Failsafe, low-cost composite structures

~$5,000

200 knot

Electric Propulsion





Electric Aircraft

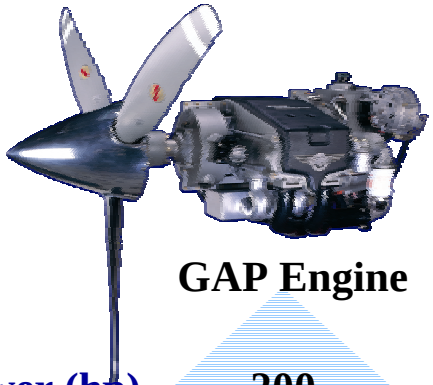
Ultra-reliable, Decoupled, Integrated
Propulsion/Flight Controls
Hydrogen Fueled
All Electric Subsystems
Proactive Health Management System

Electric Propulsion

Light Weight
Efficient
Hydrogen/Air Fuel Cell
No TBO
Ex Noise, foot print within airport
Cab Noise, like auto
Emission, “0”

Trend Setting Revolutionary Engines

(Technology Readiness Level = 6 to 7: Technology Demonstrated In 2000)



GAP Engine

FJX-2

210	Power (hp)	200
350	Weight (lb)	~350
Gasoline	Fuel	Jet
Air	Cooling	Liquid
0.45	bsfc	0.36
$30K	Cost	~$15K
1800	TBO (hr)	3000
Noisy & Harsh	Comfort	~ -5db (external) Smooth

420	Thrust (lb)	700
195	Power (hp)	~500
0.66	Weight (lb)	<100
$230K (+$30K)	bsfc	<0.5
3500	Cost	~$65K
1750	TBO (hr)	5000
Noisy	Hot Sec. (hr)	2500
	Comfort	> - 5 db (external) Very Smooth

IO 360 ES

Allison 250-B17C Turboprop

Materials

Ceramics

- 2001 SOA (typical material - AS800 (Si_3N_4)
  - 2000 to 2100˚F gas temp. (With long life)
  - Fairly blunt leading and trailing edges
  - Susceptible to oxidation and FOD (foreign object damage)
  - Expensive to manufacture
- 2007 Desired SOA
  - 2200 to 2300˚F gas temp. (With long life)
  - Aerodynamically efficient shape
  - Oxidation/erosion and FOD proof
  - Low-cost manufacturing
- Challenges
  - Life prediction tools
  - NDE for small parts with complex shapes
  - Design airfoil to prevent oxidation, erosion and FOD from causing unacceptable damage while maintaining efficient aerodynamics
  - Rapid prototyping and low-cost manufacturing methods

Materials

Polymer Matrix Composites

- 2001 SOA (typical material - PMR-15)
  - 500˚F material temp. (long life)
  - Very expensive, especially manufacture of complex shapes
  - Moisture absorption may be a problem for some applications and effect durability and decrease upper use temperature
  - Toxicity of some starting materials can pose health risks in manufacturing and repair
  - FOD tolerance

- 2007 Desired SOA
  - 650 ˚F material temp. (long life)
  - Low-cost materials and manufacturing methods
  - Non-toxic starting materials
  - Low cost, reliable repair techniques
  - Reliable, efficient life prediction tools
  - FOD proof

- Challenges
  - Life prediction tools
  - NDE for small parts with complex shapes
  - Coatings and chemistry for long term stability
  - Protection from and/or robustness to FOD
  - Repair methods
  - Low-cost manufacturing methods

Relative Sound Levels

Rocket Engine

190

180

170

160

Threshold of Pain

150

140

Sonic Boom

Overhead Jet Aircraft *(500 ft)*

130

Construction Noise

120

Subway Train

110

Hydraulic Press *(3 ft)*

Train Whistle *(500 ft)*

100

Helicopter Cabin

Light Truck in City *(20 ft)*

90

Chain Saw

Dishwasher

80

Inside a Subway Car

70 *

Heavy Traffic *(25-50 ft)*

Private Office

60

Automobile *(20 ft)*

50

Conversation

40

30

20

10

Broadcasting Studio

OSHA Noise Standards
90 dBa - 8 hrs
95 dBa - 4 hrs
100 dBa - 2 hrs

* Hearing loss may begin with continuous exposure to sound levels over 75 dBa

Noise

- 2001 SOA
  - Fixed Wing GA (4 to 6 PAX Light Aircraft)
    - = Exterior fly over - 70 to 75 dbA
    - = Interior - 90 to 100 dbA
  - Helicopter
    - = Exterior take off - 90 dbA
    - = Interior - > 100dbA

- 2001 SOA
  - Fixed Wing GA (4 to 6 PAX Light Aircraft)
    - = Exterior fly over - 65 to 70 dbA
    - = Interior - 60 to 65 dbA
  - VTOL
    - = Exterior take off - 65 to 70 dbA
    - = Interior - 60 - 65 dbA

- Challenges
  - Efficient low tip speed propellers and rotors
  - Low-noise fan and duct/nozzle technology
    - = Blade shapes, spacing, etc.
    - = Noise absorption technology
    - = Active noise control technology
  - Low noise gears
  - Propulsion structural noise and vibration isolation from cabin
  - Low-cost interior active noise control methods

Bearings, Gears and Transmissions

Bearings

- 2001 SOA
  - Turbine Engines
    = Oil lubricated roller element bearings
  - Piston Engines
    = Oil lubricated journal and roller element bearings
  - Transmissions/Gearboxes
    = Oil lubricated journal and roller element bearings
- 2007 Desired SOA
  - Turbine Engines
    = Air bearings (e.g., foil bearings)
  - Piston Engines
    = Low Oil bearing systems
  - Transmissions/Gearboxes
    = Low Oil bearing systems
- Challenges
  - Incorporating foil bearings in to complex shaft systems
  - Scaling foil bearings upward in size
  - Reducing weight, cost and power consumption of magnetic bearings
  - Advanced journal bearing technologies
  - Fluid management optimization

Bearings, Gears and Transmissions

Transmissions/Gearboxes

- 2001 SOA
  - Power output
    = ~20 hp/lb (inline)
    = ~15 hp/lb (offset)
  - ~$21/hp cost

- 2007 Desired SOA
  - 50% weight reduction in lube sys.
  - 20% weight reduction gearbox
  - 50% cost reduction

- Challenges
  - Fluid management optimization - minimize lube system requirements for packaging and weight reduction
  - High-ratio gear components and configuration technologies - component and system arrangements that permit very high gear ratio capability
  - Lightweight materials
  - Alternate mechanisms (e.g., belt drive, toroidal drive, etc.)

Small Turbomachinery

- 2001 SOA
  - Axial Compressor
    (~2 lb./sec. flow rate, 5:1 pressure ratio)
    = 79% adiabatic efficiency
  - Centrifugal Compressor
    (~2 lb./sec. flow rate, 8:1 pressure ratio)
    = 80% adiabatic efficiency
    (~2 lb./sec. flow rate, 4:1 pressure ratio)
    = 83% adiabatic efficiency

- 2001 SOA
  - Axial Compressor
    (~2 lb./sec. flow rate, 5:1 pressure ratio)
    = 81% adiabatic efficiency
  - Centrifugal Compressor
    (~2 lb./sec. flow rate, 8:1 pressure ratio)
    = 81% adiabatic efficiency
    (~2 lb./sec. flow rate, 4:1 pressure ratio)
    = 84% adiabatic efficiency

- Challenges
  - Manufacturing of small components
    = Small clearances
    = Surface finish
    = Part thickness
    = Low cost
  - Turbines
    = Increased loading
    = Low Reynold's number in aft stages

Controls and Health Monitoring

- 2001 SOA
  - Single lever power control
    = Engine protected from misuse
  - Simplified/integrate cockpit readouts
    = Can drive multifunction flat panel
  - Diagnostic system readout to ground computer after flight
    = Fault isolation
    = Trend analysis
  - ~$10,000 for full system (FADEC, displays, diagnostic system)

- 2001 SOA
  - Integrated Aircraft/Propulsion Supervisor
    = Pilot inputs direction and speed (could be point-to-point flight plan)
    = Supervisor controls and reconfigures aircraft/propulsion
    = Supervisor advises pilot of abnormal aircraft/propulsion operation, reconfigures as necessary and recommends pilot action
    = Supervisor advises pilot of external situation issues (weather, traffic, obstacles, etc.) at minimum
  - Order of magnitude cost reduction

- Challenges
  - Certification of COTS components
  - Order of magnitude reduction in sensor and actuator cost (Sensors are major cost driver)
  - Development of, and incorporation of Fault-Tolerant Control technology and fast, robust, “intelligent” controls and diagnostics
  - Bulletproof software and automated software development processes
  - Development of natural, intuitive human machine interfaces

Electric Propulsion

Fuel Cells

- 2001 SOA
  - Cost ~$500 per kw
  - Power output
    = ~1 kw/kg
    = ~1 kw/liter
  - 3000 hr life

- 2007 Desired SOA
  - Cost ~$50 per kw
  - Power output
    = ~2 kw/kg
    = ~2 kw/liter
  - 3000 hr life at high power density

- Challenges
  - Low cost materials and manufacturing methods for electrodes, electrode catalyst, membrane and bipolar plates
  - Lightweight materials
  - Certification

Electric Propulsion

Motors & Actuators

- 2001 SOA
  - Heavy

- Challenges
  - Lightweight materials
  - Efficient heat dissipation
  - Certification

- 2007 Desired SOA
  - Light weight